Energy Harvesting and Communication Systems for Power Lines Inspection Robot

Valenta Pavel, Žahour Jiří, Křivka Jindřich, Kosturik Kamil, Skála Jiří, Georgiev Vjačeslav
Department of applied electronics and telecommunications
Faculty of electrical engineering, university of west Bohemia
Plzeň, Czech Republic
valpav@kae.zcu.cz, zahourj@kae.zcu.cz, jkrivka@kae.zcu.cz, kosturik@kae.zcu.cz, skalaj@kae.zcu.cz, georg@kae.zcu.cz

***Abstract*—For an autonomic power lines inspection robot the energy harvesting system and communication systems are being developed. In this paper the energy harvesting based on toroidal split core current transformer is described. The maximal output power is depend on the current in power line, the transformer core geometry and other factors. The results from the testing and measuring of the current transformer are presented. Also the structure of the communication system is described.**

Keywords—autonomic inspection robot; current trasnformer; DC-DC converter; energy harvesting; power lines; split toroidal core; communication system; CAN; Ethernet

I. Introduction

For increase the reliability and security of the electricity transmission network backbone the condition of the power lines must be monitored and controlled. For this purpose the inspection robot is being developed. The inspection robot should be able monitor the condition of power line parts such as conductors, insulators, connecting elements and so on. For high work efficiency the robot must be able to overcome long distance without the operator intervention. For that reason is necessary to harvest energy directly from the power line conductor.

The inspection robot must be able to communicate with the operator. For systems of the inspection robot several communication channels and buses are used. These are designed for communication between subsystems of the robot and for communication with the operator. The communication system enables sending the system status information (e.g. battery state, temperature, battery charging or discharging current and so on) and information from the power lines monitoring sensors.

II. The Robot Supply System

A. Structure of the robot supply system

The main source of energy is a Li-ion battery. For battery charging the energy harvesting system is use. This system consists of the toroidal split core current transformer, rectifier and DC-DC converter.

This paper includes results created within the project TH02020319 and SGS-2018-001. The projects are subsidized by the Technology Agency of the Czech Republic, and the Ministry of Education, Youth and Sports from the European Regional Development Fund and resources of the state budget of the Czech Republic.

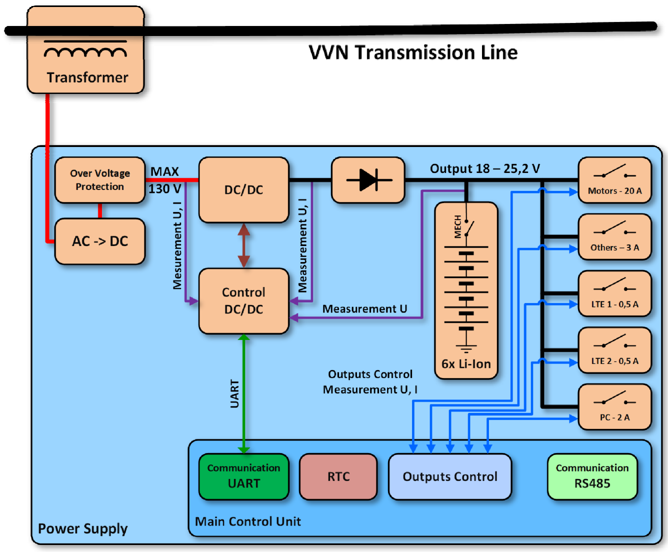

Fig. 1. Structure of the robot supply system.

The secondary voltage of the current transformer is rectified and converted by the DC-DC converter. DC-DC converter implements the MPPT (Maximum Power Point Tracking) algorithm. Other robot subsystems are supplied by the power management system. The block diagram of the robot supply system is shown in Fig. 1.

B. Current transformer

The current transformer is key part of the robot supply system. The Core volume and geometric arrangement determine maximum achievable output power. The transformer weight and conductor dimensions are limiting factors for transformer size. Based on the theoretical analysis (e.g. [1]-[6]) a prototype of a current transformer was designed. To insert and remove the transformer on the conductor and to overcome obstacles on the power line (e.g. insulator, connecting elements and so on) the transformer core is split. For experimental purposes the current transformer has two separate windings (10 + 20 and 20 + 20 turns). The current transformer placed in plastic housing is shown in Fig. 2.

978-1-7281-9479-0/20/$31.00 ©2020 IEEE

Authorized licensed use limited to: Univ of West Bohemia in Pilsen. Downloaded on December 07,2020 at 12:04:09 UTC from IEEE Xplore. Restrictions apply.

Fig. 2. The current transformer placed in housing.

The core outer diameter is 82 mm, inner diameter is 45 mm, and core length is 70 mm. The core weight (without the housing) is 1.8 kg.

III. THE CURRENT TRANSFORMER MEASUREMENT

In order to obtain information about the behavior of the proposed current transformer, measurements were carried out. It was also necessary to determine the optimum number of the secondary turns.

A. *Experimental measuring assembly*

Perform measurement on the really power line is not possible for safety reason. For this reason an experimental measuring assembly was assembled. The experimental measuring assembly simulates the current in the power line. The measuring assembly consists of 3-phase DC-AC convertor loaded by resistors. There is the current transformer on one phase conductor. The current transformer is loaded by variable resistor. The transformer secondary voltage and current are measured. The measuring assembly block diagram is shown in Fig. 3. On this measuring assembly was measured volt-ampere characteristics and output power dependency on the primary current. In Fig. 4 is a photograph of the real measurement assembly.

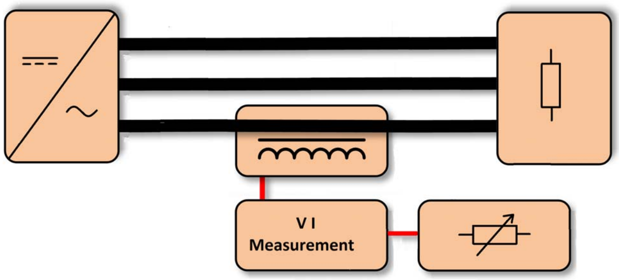

Fig. 3. The measuring assembly block diagram.

Fig. 4. The real measuring assembly.

B. *Measurements results*

The maximum power depends on the primary current (i.e. the current in the power line conductor). The load characteristic was measured for different primary current values.

For primary current in range from 20 to 100 A and for different number of secondary turns the load characteristics were measured. The measured load characteristics are placed into one graph for comparison. The graph is shown in Fig. 5. In Fig. 6 the output power for different number of primary turns and different primary current is shown.

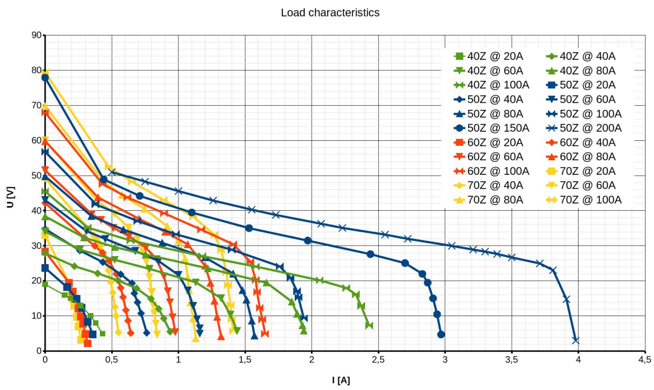

Fig. 5. The current transformer load characteristics.

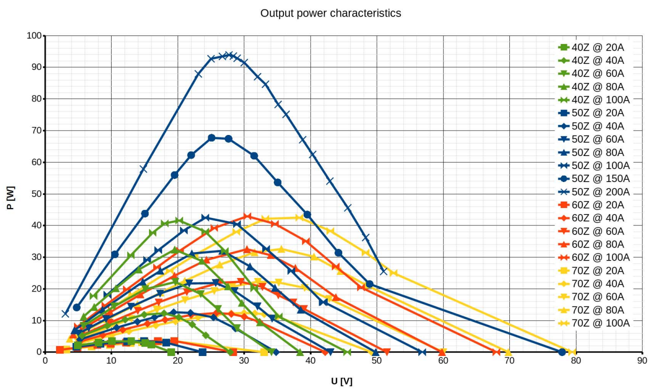

Fig. 6. The current transformer power characteristics.

Authorized licensed use limited to: Univ of West Bohemia in Pilsen. Downloaded on December 07,2020 at 12:04:09 UTC from IEEE Xplore. Restrictions apply.

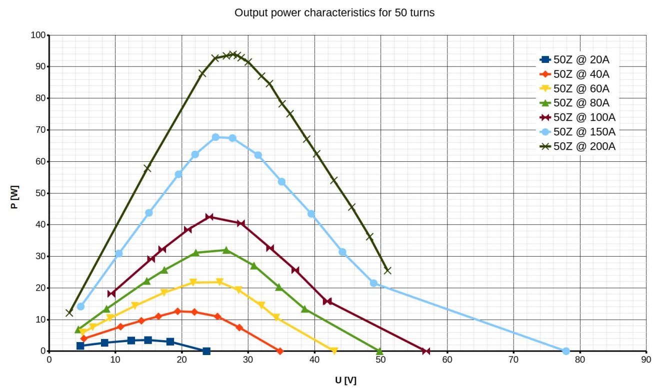

Fig. 7. The current transformer power characteristics for 50 turns of secondary winding.

As can be seen from the Fig. 5 the maximum output power (at the constant primary current) can be achieved at optimum load of the current transformer. With respect to the expected primary current and optimal secondary voltage the 50 turns secondary winding seems to be the most appropriate. The output power dependency for 50 turns winding is shown in Fig. 7.

IV. DC-DC CONVERTER

The current transformer secondary voltage is rectified and filtered and applied to the input of DC-DC convertor. Also an overvoltage protection is included. The secondary voltage depends on the transformer load and primary current. The DC-DC converter must be able to increase or decrease the input voltage. The simplified diagram of used DC-DC converter is shown in Fig. 8. This topology is known as a buck-boost converter.

In Fig. 7 can be seen the maximum power points for different value of the primary current. Maximum power can be achieved at a certain secondary voltage. However, for different primary currents this voltage is different. For this reason is necessary to use MPPT (Maximum Power Point Tracking) algorithm for DC-DC converter controlling. The DC-DC converter changes the load for the current transformer and tracks the maximum power point.

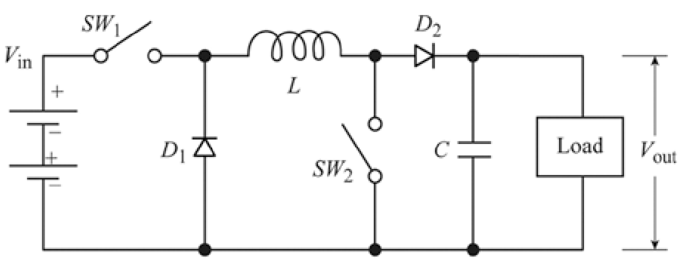

Fig. 8. The simplified diagram of buck-boost converter topology.

V. COMUNICATION SYSTEM

For the autonomic power line inspection robot is used several communication buses and protocols as shown in Fig. 9. The core of the robot is a central control computer that will communicate with other electronic units through the CAN bus. It includes the communication with the charging and power supply unit. This unit sends information about the battery status, charging/discharging current and consumption of the whole robot. Next CAN connected is a drive control unit that controls the movements of the robot. IP cameras and combined LTE/Wi-Fi modem are connected with the central computer by an Ethernet bus.

The primary communication channel to the internet is LTE connection. The Wi-Fi connection is used only as a backup. The modem tries to establish a secure VPN connection to a central server. An operating data are periodically stored in the central server. A control application on this server enables to send commands to the robot. Also a visualization interface designed as WWW pages running in the server.

VI. THE TEST ASSEMBLY

For real testing of designed energy harvesting and communication system the test assembly was build. The test assembly consists of the split core current transformer, DC-DC converter, small battery pack and dummy load for measurement achievable power on real power line. Also the modem for communication is placed in testing assembly. The test assembly is shown in Fig. 10.

Before placing the test assembly on real power line the immunity to the strong electric field was tested in a high-voltage laboratory. During this testing also the functionality of the communication system near the strong electric field was verified. After these tests the test assembly was hanged on a real power line.

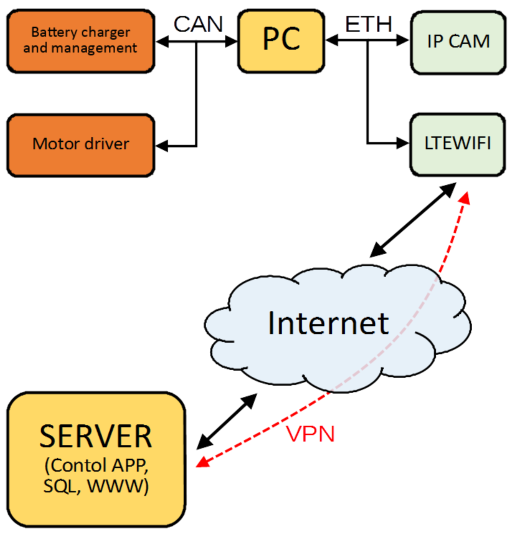

Fig. 9. The block diagram of the robot communication system.

Authorized licensed use limited to: Univ of West Bohemia in Pilsen. Downloaded on December 07,2020 at 12:04:09 UTC from IEEE Xplore. Restrictions apply.

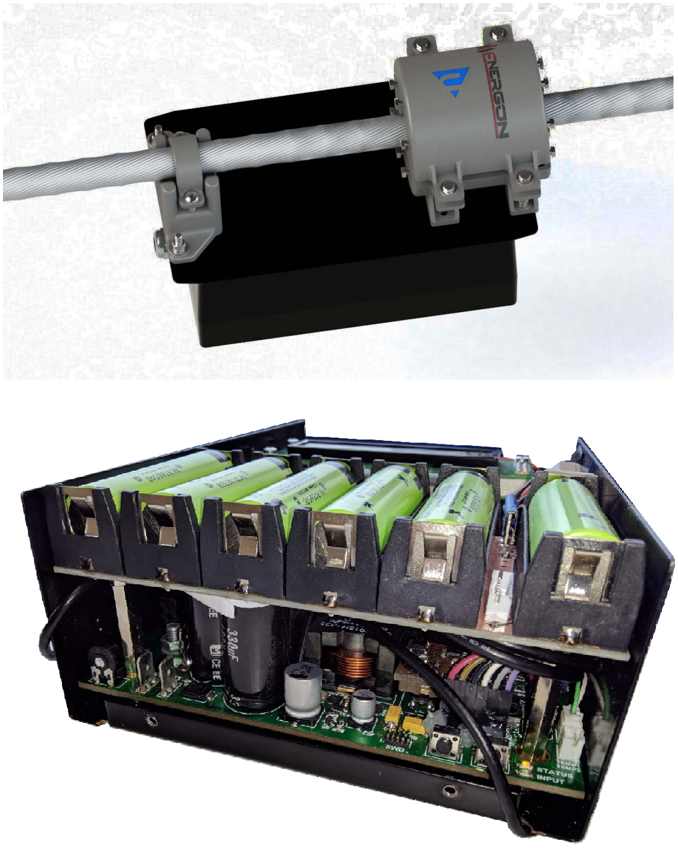

Fig. 10. The test assembly.

VII. Testing on the Real Power Line

After laboratory testing the test assembly was tested on the real power line. The testing was carried out on a 110 kV power line. On the power line was testing the functionality of the whole assembly. The batteries were charged by the DC-DC converter with current transformer. The operating data was sent and stored to the server. The demonstration of the web interface with data stored during real testing is shown in Fig. 11.

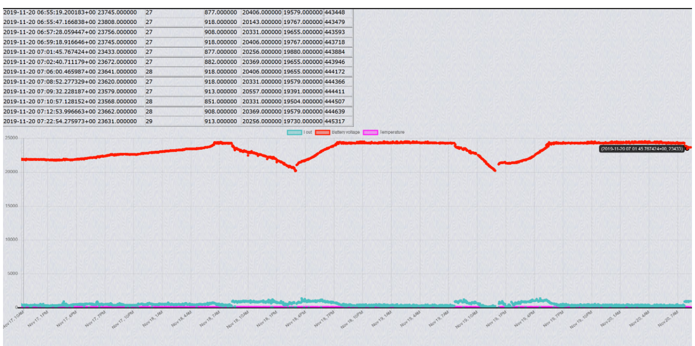

Fig. 11. Demonstration of data recorded on real power line 110 kV.

VIII. Conclusion

The solution of power line energy harvesting by using split core current transformer was the goal of this work. The current transformer with toroidal split core was designed and made. The measurements for this transformer were carried out under laboratory conditions. The maximum power that can be obtained exceeds 90 W at 200 A power line current. Next was designed the test assembly for testing on the real power line.

The testing assembly consists of the DC-DC converter, battery pack and communication system. First the test assembly was tested for resistance to strong electric field. Then the real testing on 110 kV power line was carried out. During this testing was verified the functionality of energy harvesting system and communication system under real conditions. The real test lasted two weeks. The maximal output power is depend on the current in power line and is variable. All the time the test assembly was able to charge the batteries.

The measured data was sent and save to the server and on the local FLASH memory. After testing the memory data and server data was compared. No difference between data from FLASH and sent data was found. It suggests that there was no communication problem during the test.

References

[1] Ahola, Jero & Ahonen, Tero & Sarkimaki, V. & Kosonen, Antti & Tamminen, J. & Tiainen, Risto & Lindh, T.. (2008). Design Considerations for Current Transformer Based Energy Harvesting for Electronics Attached to Electric Motor. 901 - 905. 10.1109/SPEEDHAM.2008.4581191.

[2] Zhi-Min, He & Tian-Chen, Yue & Ya-Dong, Liu & Ge-Hao, Sheng & Xiu-Chen, Jiang & Ying-Bin, Zhang & Shu-Qin, Li & Qiang, Wang. (2013). Study on Power Supply System by Using CT in High-Voltage Transmission Lines. Research Journal of Applied Sciences, Engineering and Technology. 6. 3859-3864. 10.19026/rjaset.6.3602.

[3] Yang, Mingbo & Liang, Zize & Qian, Hanbo & Li, En & Yang, Guodong. (2012). Design and Analysis of Multi-Winding Power Current Transformer for Power Transmission Lines Inspection Robot. Procedia Engineering. 29. 2187-2193. 10.1016/j.proeng.2012.01.285.

[4] Yang, Mingbo & Liang, Zize & Li, En & Zhang, Kailiang & Yang, Guodong. (2011). Design of Current Transformer for Power Transmission Lines Inspection Robot. 10.1007/978-3-642-21747-0_93.

[5] Peng, Wang & Feng, Liu & Guanqun, Wang & Kefei, Wang & Shengwei, Mei. (2010). Research on Self-Power Supply System of Inspection Robot for High-Voltage Power Transmission Lines. Advanced Technology of Electrical Engineering and Energy. 30. 244 - 247. 10.1109/ISDEA.2010.178.

[6] Yao, Min & Zhao, Min. (2013). Research on electric energy harvesting from high-voltage transmission line. 1-4. 10.1109/EPECS.2013.6713052.

Authorized licensed use limited to: Univ of West Bohemia in Pilsen. Downloaded on December 07,2020 at 12:04:09 UTC from IEEE Xplore. Restrictions apply.